From Microns to Millimeters: the Use of Optically Determined Particle Size and Distribution in Understanding Coastal Vertical Mixing Processes

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LONG-TERM GOALS

This is a continuation of a project with Dr.'s W.D. Gardner and M.J. Richardson at Texas A&M University. Our long-term goals are 1) to determine how changes in particle size distribution, composition and concentration on the shelf affect inherent optical properties (attenuation, absorption and scattering) and 2) correlate these measurements with hydrographic measurements (including wave and current shear stress as measured by others) to determine the forcing functions and biological processes that cause the temporal and spatial variations in optical properties on the shelf.

OBJECTIVES

1. Determine the relationship between inherent optical and particle characteristics (composition, mass concentration, and size distribution) for the area studied during the Coastal Mixing and Optics (CMO) Advanced Research Initiative (ARI).
2. Determine how the above relationships vary between periods of high stratification (late summer) and low stratification (early spring) conditions.
3. Determine the significance of the presence of large aggregates on the inherent optical properties.

APPROACH

We collected time-series data on particle concentration, composition and size, hydrography, and in-situ optical properties at the central CMO site on the continental shelf south of Cape Cod, Massachusetts during periods of high (Fall '96) and low (Spring '97) stratification. Our data are being interpreted in the context of measurements made by others such as turbulence intensity; currents (shipboard ADCP and moored current meters, bottom shear stresses, and SeaSoar measurements at various space scales around the CMO site to ascertain the roles of mixing, advection, primary particle production, aggregation and resuspension on the relationships between particle and optical properties of the water in that region.

Our Particle and Optics Profiling System (POPS) integrates several different instrument packages. A SeaBird SeaCat CTD provided a synoptic hydrographic context in which to place our particle and optical measurements. Integrated with the CTD was a SeaTech transmissometer (λ=660nm) to provide in-situ optical data about the concentrations and particle types in the water. Most of the attenuation signal comes from particles < 20 µm in size. To determine the dissolved and particulate contributions to inherent optical properties, we measured both filtered (0.2 µm) and unfiltered absorption and attenuation during the spring cruise. A Sequoia Scientific LISST 100 was used to estimate the size

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distribution of particles from 5-500 µm in summer and 1.25-250 µm in spring. To measure the size and abundance of large aggregates, we developed a dual video camera and synched-strobe system that illuminates and video records two separate volumes of water. The close-up, small-volume video is used to discriminate aggregates as small as 300 µm and the larger-volume system images aggregates >500 microns. Thus, on a single platform we have a series of instruments that measure the particle spectrum from a few microns to several millimeters as well as important hydrographic (temperature, salinity, and pressure) and optical parameters.

It is essential to make in-situ measurements of aggregates because they can fall apart from the slightest disturbances, thus altering the true particle size distribution. Individual phytoplankton are more likely to survive water bottle collection intact and bulk particle concentrations are less prone to sampling bias. To correlate optical measurements with particle size distribution, concentration and particle types, we collected samples from the CTD/rosette profiles at discrete depths. Particle samples were collected by passing the water through preweighed 0.4 µm filters to determine concentrations of particulate matter (PM), and through precombusted glass fiber filters to determine concentrations of particulate organic carbon (POC). We measured the abundance and size distribution of particles in water samples using a Coulter Multisizer. Comparisons of particle size were made between the water-column particles, surface sediments and settling particles by collecting cores and deploying sediment traps during each cruise. Physical and optical measurements will be integrated to achieve the objectives outlined above.

WORK COMPLETED

We participated on a cruise to the CMO site (the continental shelf south of Cape Cod, Massachusetts) during late summer (August 18 to September 7, 1996) stratified conditions, and a second cruise after winter mixing (23 April-9 May, 1997) as stratification began. CTD profiles were made just during the day, but we combined nighttime temperature and salinity data from Dr. M. Gregg's (UW) profiling system to create time-series hydrography-transmissometer-fluorometer sections. We filtered bottle samples for particulate matter (PM) and particulate organic carbon (POC) to make correlations with other discrete and optical parameters. Dr. Collin Roesler (U.Conn.) determined the pigment concentration for the bottle samples using fluorometric techniques. Particle sizes from 1-25 µm were measured from bottle samples using a Coulter Multisizer. A short-term sediment trap mooring using cylindrical sediment traps recorded mass flux during the first 2 weeks of each cruise and gravity cores provided samples of surface sediment. POPS and CTD/rosette casts were made routinely 3-12 times a day during the occupation of the 70 m deep central station at 40.5 °N, 70.5 °W. Transects were made across the shelf from about 40 m to 1000 m to determine regional variability.

RESULTS

The two cruises provided excellent time series observations of stratified summer conditions (stirred dramatically by the passage of Hurricane Edouard at the end of the cruise) for comparison with low-stratified spring conditions. Upon our arrival in the spring, the water column was nearly mixed due to winter storms, but was still a distinct 2-layer system which further stratified during the cruise to a 3-layer system due to solar heating even though several nor'easters passed through the area. Surface-water particle concentrations were 20-25% higher in the spring than in the summer, and pre-hurricane bottom water particle concentrations were about 60% greater in the summer. Particle fluxes measured with sediment traps were greater in the spring than in the summer at the same depths. This may have resulted from undertrapping of the smallest sized particles during the summer, as size fraction analysis of the settled material indicates comparitively little flux in the <63µm fraction in the summer as compared to the spring. Resuspension and aggregate rebound were greater in the summer than the spring (Fig. 1)

which would suggest higher particulate fluxes in the fall in the near bottom traps. Aggregate abundance was lower in the spring than the fall, but skewed towards larger diameter aggregates. Results from co-investigators showed higher current velocities during the fall cruise as compared to the spring, and it is possible that this resulted in undersampling of the smaller and slower settling particles.

The ADCP data showed periods of strong horizontal shear as internal waves or solibors generated at the shelf break passed the site in the summer, but these waves were not clearly observed in the spring. These events may be important for the generation and/or re-distribution of aggregates and the resultant impact on inherent optical properties of the water column.

Correlations between bulk particle properties (PM and POC concentrations) and optical properties were poor during highly stratified periods because stratification created numerous small layers of particles with different particle characteristics (composition, size, shape). Correlations were very different for near-surface versus near-bottom waters. After the passage of Hurricane Edouard the water column was mixed to a two-layer system in which correlations were very good, though different, in the two layers. The mean size of particles <20 μm decreased in bottom waters after the hurricane, decreasing the beam attenuation to PM ratio by 50%. The above correlations were much better during the spring when there was a 2-3 layer system, but the correlations were still different in each water mass, suggesting different particle types. The first aggregate profile after the hurricane measured a much lower aggregate concentration than previous or subsequent profiles. Within the benthic boundary layer the increase in aggregate abundance and size was matched by a decrease in the beam attenuation, suggesting that aggregation kinetics were at least partially responsible for the apparent clearing of the water collumn.

Generally, the aggregate distribution reflected the two or three layer water column, with the near surface layer being characterized by increasing aggregate concentrations from the surface to the pycnocline along with an increase in the relative abundance of the largest aggregates. Intermediate aggregate nepheloid layers were frequently found above the benthic boundary layer, indicative of aggregate rebound at an upstream location and subsequent advection to the site. These features were often found without a corresponding increase in beam attenuation, and sometimes were associated with a decrease in beam attenuation. Within the benthic boundary layer aggregate abundance was observed to increase with increasing beam attenuation.

IMPACT/APPLICATION

It is more difficult to predict the optical properties of a stratified column of water than a well-mixed body of water given the bulk composition and concentration of particles within the water. During strongly stratified periods, events of hurricane force were required to cause significant vertical mixing, although the passage of solibors also had an effect in the upper water column. When the water was only weakly stratified in the spring, nor'easters (with winds over 30 kt) caused only surface mixing: stratification increased as surface waters were heated during a two-week period despite frequent storms. Although particles in the upper water column may grow (primary production), remineralize, aggregate or settle to the lower water column, even minor stratification prevents mixing of particles from the lower layers to the upper layers, though wintertime mixing may extend throughout the water column.

TRANSITIONS

The profiling instruments and software (partially developed under NSF and DOE funding) were used in the JGOFS Southern Ocean biogeochemical process studies. The camera system was used in the North

Water Polynya project. The camera system will be used in an upcoming NSF project exploring Th uptake and aggregation dynamics.

RELATED PROJECTS

1 – A sediment trap study with periodic water column optical work (beam attenuation, and backscatter) is being conducted on the outer continental shelf of the eastern Gulf of Mexico. Preliminary results suggest that, as with the CMO data set, intrusions of shelf water and storm events have a major impact on particle dynamics.

2 - A study of particle dynamics in the North Water polynya in northern Baffin Bay using annual sediment traps, short term floating traps, water column CTD/transmissometer and aggregate imaging techniques suggests that vertical mixing is most likely a significant forcing function for particle fluxes and dynamics in that region.

3 – The same optical and particle measurements were made in the upper water column of the Southern Ocean and are being correlated with hydrography, stratification and biogeochemical measurements to quantify carbon production, distribution and loss.

PUBLICATIONS

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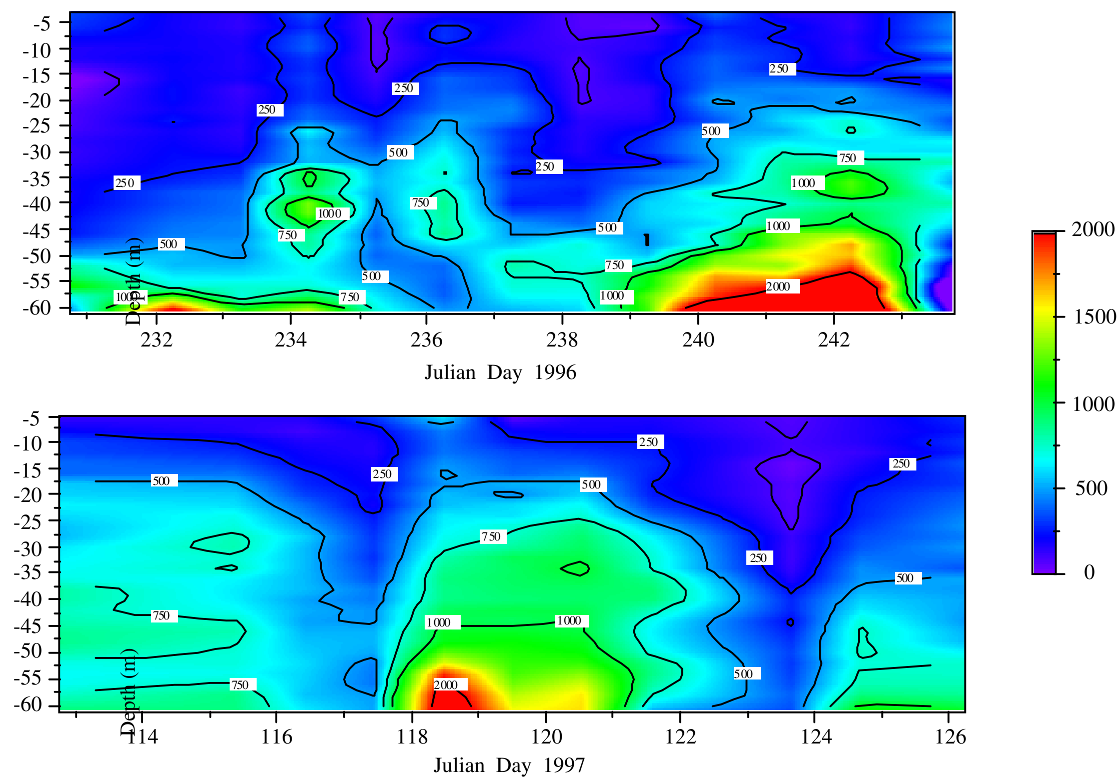

Figure 1. Aggregate abundance (aggregates per liter) at the CMO central station during the two cruises descrbed in the text. Note that the summer data is all prior to the hurricane.